

Climate Catastrophe

A Superstorm for Global Warming Research

By Marco Evers, Olaf Stampf and Gerald Traufetter

Plagued by reports of sloppy work, falsifications and exaggerations, climate research is facing a crisis of confidence. How reliable are the predictions about global warming and its consequences? And would it really be the end of the world if temperatures rose by more than the much-quoted limit of two degrees Celsius?

Life has become "awful" for Phil Jones. Just a few months ago, he was a man with an enviable reputation: the head of the Climate Research Unit (CRU) at the University of East Anglia in Norwich, England, an expert in his field and the father of an alarming global temperature curve that apparently showed how the Earth was heating up as a result of anthropogenic global warming.

Those days are now gone.

Nowadays, Jones, who is at the center of the "Climategate" affair involving hacked CRU emails, needs medication to fall sleep. He feels a constant tightness in his chest. He takes beta-blockers to help him get through the day. He is gaunt and his skin is pallid. He is 57, but he looks much older. He was at the center of a research scandal that hit him as unexpectedly as a rear-end collision on the highway.

His days are now shaped by investigative commissions at the university and in the British Parliament. He sits on his chair at the hearings, looking miserable, sometimes even trembling. The Internet is full of derisive remarks about him, as well as insults and death threats. "We know where you live," his detractors taunt.

Jones is finished: emotionally, physically and professionally. He has contemplated suicide several times recently, and he says that one of the only things that have kept him from doing it is the desire to watch his five-year-old granddaughter grow up.

'100 Percent Confident'

One of the conclusions of his famous statistical analysis of the world's climate is that the average temperature on Earth rose by 0.166 degrees Celsius per decade between 1975 and 1998. This, according to Jones, was the clear result of his research and that of many other scientists.

"I am 100 percent confident that the climate has warmed," Jones says imploringly. "I did not manipulate or fabricate any data."

His problem is that the public doesn't trust him anymore. Since unknown hackers secretly copied 1,073 private emails between members of his research team and published them on the Internet, his credibility has been destroyed -- and so has that of an entire profession that had based much of its work on his research until now.

Those who have always viewed global warming as a global conspiracy now feel a sense of satisfaction. The so-called climate skeptics feel vindicated, because Jones, in his written correspondence with colleagues, all of them leading members of the climate research community, does not come across as an objective scientist, but rather as an activist or missionary who views "his" data as his personal shrine and is intent on protecting it from the critical eyes of his detractors.

An Entire Branch of Science in Crisis

The Climategate affair is grist for the mills of skeptics, who have gained growing support for their cause, particularly in English-speaking countries. What began with hacked emails in the United Kingdom has mushroomed into a crisis affecting an entire scientific discipline. At its center is an elite and highly influential scientific group, the Intergovernmental Panel on Climate Change (IPCC).

Working on behalf of the United Nations, the scientists organized under IPCC's umbrella -- including Phil Jones -- regularly prepare prognoses on the Earth's looming greenhouse climate. Without the IPCC reports, governments would not be embroiled in such passionate debate about phasing out the age of oil and coal.

In late 2007, the IPCC was even awarded the Nobel Peace Prize jointly with former US Vice President Al Gore. IPCC Chairman Rajendra Pachauri, as the personification of the world's conscience, accepted the award on behalf of his organization. "Climate change poses novel risks," Pachauri told his audience, saying that the decision to award the prize to the IPCC was "a clarion call for the protection of the earth as it faces the widespread impacts of climate change." He also warned of the risk of not taking action: "Every year of delay implies a commitment to greater climate change in the future."

Sloppy Work

Since then, the IPCC has experienced a dramatic fall from grace. Less than three years after this triumph, more and more

mistakes, evidence of sloppy work and exaggerations in the current IPCC report are appearing. They include Jones' disputed temperature curve, the prediction that all Himalayan glaciers would disappear by 2035 -- which was the result of a simple transposition of numbers -- and the supposed increase in natural disasters, for which no source was given.

In mid-March, UN Secretary General Ban Ki Moon slammed on the brakes and appointed a watchdog for the IPCC. The InterAcademy Council, a coalition of 15 national academies of science, will review the work of the IPCC by this fall.

There is already a consensus today that deep-seated reforms are needed at the IPCC. The selection of its authors and reviewers was not sufficiently nonpartisan, there was not enough communication among the working groups, and there were no mechanisms on how to handle errors.

Offering the Skeptics an 'Unprotected Flank'

Also at issue is the position of IPCC Chairman Rajendra Pachauri, who is praised as a "leading global thinker" in his official biography. A railroad engineer by trade, Pachauri wrote an erotic novel and recommended that people reduce their meat consumption while traveling around the world to save the climate. He has cut a miserable figure during the current crisis. The climate guru summarily dismissed justified objections to the IPCC report as "voodoo science."

Germany's Leibniz Association, an umbrella group which includes several climate research institutions as its members, is the first professional organization to call for Pachauri's resignation. Leibniz President Ernst Rietschel believes that climate research is now "in a difficult situation" because the skeptics have been "offered an unprotected flank." Rietschel told SPIEGEL: "Rajendra Pachauri should take the responsibility for this and should resign."

On balance, the entire profession has been seriously harmed by the scandal. "We are currently suffering a massive erosion of trust," concludes German climatologist Hans von Storch. "Climate research has been corrupted by politicization, just as nuclear physics was in the pre-Chernobyl days, when we were led to believe that nuclear power plants were completely safe."

Politically Charged Science

No other branch of science is as politically charged. A religious war is raging between alarmists and skeptics, and it threatens to consume levelheaded climatologists. But it is a critical conflict, because it revolves around something as massive as the total restructuring of industrial society, a venture that will cost trillions of euros. Powerful economic interests and unshakeable fundamental beliefs come into play.

The credibility crisis in climatology comes at an extremely unfavorable time. Since the failed December 2009 climate summit in Copenhagen, environment policy has been in a state of shock. US President Barack Obama, for example, has put his initiative for new climate legislation on hold. And last week French President Nicolas Sarkozy reversed his plans to introduce a climate tax, saying: "We will not impose any constraints on our industry yet."

On the other hand, Mohamed Nasheed, the president of the Maldives, an island nation threatened with extinction as a result of rising sea levels, accuses the Americans of engaging in intrigue to make climatology seem ridiculous. During a recent speech in Berlin, Nasheed characterized efforts to discredit climate research as "a diabolical plan."

Unwilling to Pay

Meanwhile, there are growing concerns in Berlin that German citizens could become less willing to pay for costly efforts to protect the climate. A poll conducted on behalf of SPIEGEL already signals a dramatic shift in public opinion and suggests that Germans are losing their fear of climate change. The strong majority of 58 percent who said they feared global warming about three years ago has declined to a minority of 42 percent.

German Environment Minister Norbert Röttgen, a member of the center-right Christian Democratic Union (CDU), is urging the IPCC to deal with its own errors more proactively. "The IPCC should openly admit its mistakes and correct them," he told SPIEGEL. "It is imperative that trust in the work of the IPCC be restored as quickly as possible."

There are also growing concerns at Germany's Ministry of Education and Research, which is spending €250 million (\$338 million) to support climate science this year. Research Minister Annette Schavan has already summoned German IPCC scientists to attend a "meeting to clarify the situation and improve quality assurance." Officials at the ministry are horrified over how unprofessionally the IPCC is organized. "The IPCC's results must be above suspicion, because their impact can cost trillions and have serious political consequences," says Wilfried Kraus, a senior ministry official.

Scientists Who Want to be Politicians

Reinhard Hüttel, head of the German Research Center for Geosciences in Potsdam near Berlin and the president of the German Academy of Science and Engineering, believes that basic values are now under threat. "Scientists should never be as wedded to their theories that they are no longer capable of refuting them in the light of new findings," he says. Scientific research, Hüttel adds, is all about results, not beliefs. Unfortunately, he says, there are more and more scientists who want to be politicians.

"If the revelations about the affair in England turn out to be true, it will be a catastrophe for climatology as a whole," says Hüttel. "We can only monitor ourselves, and if we fail in that endeavor, who can be expected to believe us anymore?"

The British climate research center the Met Office has decided that the only way to regain lost trust is to make all climate

data available online immediately, in a system that is accessible to anyone, offers maximum transparency and includes critical assessments on how reliable each piece of information is. The Met Office estimates that this major international project will take at least three years.

Despite the controversy, most climatologists agree that in the end the general view of climate change will not have changed significantly. Almost all share the basic conviction that we are headed for warmer times.

Open Questions

Scientists fear that without an open, honest process, they will no longer find a sympathetic ear. This process could mean that much of what has long been considered established knowledge will come under review once again, specifically, five elementary questions on the future of the climate:

- By how many degrees has the Earth's temperature already increased, and how much further will temperatures rise?
- How high will sea levels rise in a greenhouse climate?
- Can we expect to see storms of unprecedented strength in the future?
- Which parts of the world will experience more droughts, and where will there be more flooding?
- Will the situation on the planet truly spin out of control if the average global temperature increases by more than two degrees Celsius?

Anyone who speaks with leading climatologists today will discover how many questions remain open. The media, politicians and even scientists often talk about changes to the weather with a certainty that does not in fact exist.

A Climate Rebel Takes on the Establishment

One man notes with particular satisfaction how Phil Jones and his colleagues are being forced to confess to one mistake after another. Steve McIntyre lives in a small brick house near downtown Toronto. It is a Sunday afternoon and he is sitting at his well-worn desk, illuminated only by a small energy-saving bulb on the ceiling.

This man, with his thinning gray hair, is an unlikely adversary for climatologists, and yet he is largely responsible for the current tumult in their field. "This is the computer I used to begin doing the recalculations," he says, holding a six-year-old Acer laptop with a 40-gigabyte hard drive. "My wife finally gave me a new one for Christmas."

The laptop marks a sharp contrast to the supercomputers at the disposal of Phil Jones and the other prophets of global warming, whose computers fill entire floors. Instead of gigabytes, they deal in petabytes. How is possible that this Canadian was able to bring such a self-confident group of scientists to their knees?

It all began when his three children went off to college and moved out of his house, which is filled with Asian antiques. "Things weren't going so well in the markets at the time," says McIntyre, "so I took six months to examine how climatologists arrive at their curves."

Hitting Pay Dirt

McIntyre normally works in the investment field, specializing in major mining projects. He has always been good at math. "I won mathematics prizes in school," says McIntyre. But after finishing his studies, which included a spell at the UK's elite Oxford University, he left the academic world for a career in high finance.

His late return would shake the academic world to its core. One day, McIntyre came across a curve that seemed all too familiar to him. It was the famous hockey stick curve (see graphic), with which US climatologist Michael Mann sought to prove that, during the last millennium, temperatures have never increased as sharply as they are rising today.

But McIntyre was suspicious. "In financial circles, we talk about a hockey stick curve when some investor presents you with a nice, steep curve in the hope of palming something off on you."

The stubborn Canadian pestered one scientist after another to provide him with raw data -- until he hit pay dirt and discovered that the hockey stick curve was, in his opinion at least, a sham.

Too Few Trees

The climate historians working with Michael Mann used tree rings as the primary source of their data. The problem with this approach is that large numbers of trees from suitable regions are required if conclusions about past temperatures based on tree growth are to be drawn. "Unfortunately, if we go back more than 500 years, we don't have many reliable trees for our analyses," explains Jan Esper of the University of Mainz in western Germany.

For example, there are many indications that in medieval times, between 900 and 1,300 A.D., when the Vikings raised livestock in Greenland and grape vines were cultivated in Scotland, it was in fact warmer than it is today. This is precisely what Mann denied, with a certainty that irritated even his allies.

McIntyre put the Mann curve to the arithmetic test. He accuses Mann of having filtered out the hockey stick graph more or less arbitrarily from the fluctuation noise of his tree-ring data. To prove his contention, McIntyre programmed his computer using Mann's methodology and entered completely random data into the program. The results, says McIntyre, "was a hockey stick curve."

Then the Canadian rebel turned his attention to the far more important temperature curves of the recent past, those of

Phil Jones and of his comrade-in-arms at NASA, James Hansen. All things considered, the blunders he discovered at first were not particularly significant, but they were all the more embarrassing. For instance, scientists had long claimed that 1998 was the warmest year in the United States since temperatures were first recorded -- until McIntyre discovered that it was even warmer in 1934.

'Playground Bully'

McIntyre's findings did not make him very popular. In the hacked Climategate emails, he is referred to as a "bozo," a "moron" and a "playground bully." But with their self-aggrandizement, the climatologists made him into a legend on the Internet. A million people a month visit his blog, climateaudit.org. They include climate skeptics and the usual conspiracy theorists, but also, more recently, many academics who are able to do the math themselves.

McIntyre asserts that he does believe in climate change. "I don't want to throw the baby out with the bath water," he says, "but when I find mistakes, I want them to be corrected."

He repeatedly bombarded Jones with emails in which he drew his attention to freedom of information laws. This tenacity would prove to be disastrous for Jones.

McIntyre doggedly asked for access to the raw data. Jones was just as dogged in denying his requests, constantly coming up with new, specious reasons for his rejections. Unfortunately for Jones, however, McIntyre's supporters eventually included people who know how to secretly hack into computers and steal data.

Their target was well selected. Jones was like a spider in its web. Almost every internal debate among the climate popes passed through his computer, leaving behind a digital trail.

The Smoking Gun of Climatology

Most of all, however, Jones controlled the "smoking gun" of climatology: the Earth's temperature curve. The temperature records dating back to the beginning of industrialization are intended to prove that the average global temperature has already increased by almost one degree Celsius since 1850.

There are various pieces of indirect evidence that support the theory of global warming. Glaciers are receding, sea levels are rising and sea ice in the Arctic regions is disappearing. But these signs are nothing compared with the readings taken at weather stations.

The problem is that the quality of the raw data derived from weather services around the world differs considerably. At a number of weather stations, temperatures rose because houses and factories had been built around them. Elsewhere, stations were moved and, as a result, suddenly produced different readings. In all of these cases, Jones had to use statistical methods to correct the errors in the temperature readings, using an approach called "homogenization."

Did Jones proceed correctly while homogenizing the data? Most climatologists still believe Jones' contention that he did not intentionally manipulate the data. However, that belief will have to remain rooted in good faith. Under the pressure of McIntyre's attacks, Jones had to admit something incredible: He had deleted his notes on how he performed the homogenization. This means that it is not possible to reconstruct how the raw data turned into his temperature curve.

'One of the Biggest Sins'

For Peter Webster, a meteorologist at the Georgia Institute of Technology in Atlanta, this course of events is "one of the biggest sins" a scientist can commit. "It's as if a chef was no longer able to cook his dishes because he lost the recipes."

While amateur climatologist McIntyre spent years begging in vain for the raw data, Webster eventually managed to convince Jones to send them to him. He is the only scientist to date who has been given access to the data. "To be honest, I'm shocked by the sloppy documentation," Webster told SPIEGEL.

Unnoticed by the public, Webster has spent several months searching for inconsistencies in the Jones curve. For example, it has been known for some time that there are noticeable jumps in ocean temperature readings. The reason for the inconsistencies is that, beginning in the 1940s, water temperature was no longer measured in buckets filled with seawater, but at the intake valves for the water used to cool ship engines.

But when he analyzed Jones's data, Webster discovered suspiciously similar jumps in temperature -- but on land. "Water buckets can't explain this," says Webster.

Curious Inconsistencies

The Jones team attributes another sudden jump in temperature readings to the decline in air pollution since the 1970s as a result of stricter emissions laws. Particles suspended in the air block solar radiation, so that temperatures rise when the air becomes cleaner. Air pollution in the south has always been much lower than in the north, because, as Webster explains, "there is less land and therefore less industry in the Southern Hemisphere."

Oddly enough, however, the temperature increase in the south is just as strong as it is in the north. "That isn't really possible," says Webster.

Webster doesn't believe that inconsistencies like these will invalidate the Jones curve altogether. "But we would like to know, of course, what's behind all of these phenomena." If a natural mechanism were at least partly to blame for the rise

in temperatures, it would decrease the share of human influence in current global warming.

Urban Heat

Critics reproach Jones for not taking one factor, in particular, sufficiently into account: the growth of urban areas. Stations that used to be rural are now in cities. And because it is always warmer in cities than outside, the temperatures measured at these stations are bound to rise.

Environmental economist Ross McKittrick, one of McIntyre's associates, examined all rapidly growing countries, in which this urban heat effect was to be expected, and found a correlation between economic growth and temperature rise. He submitted his study in time for the last IPCC report.

Jones did everything he could to suppress the publication, which was critical of him. It proved advantageous to him that he had been one of the two main authors of the temperature chapter. In one of the hacked emails, he openly admitted that he wanted to keep this interfering publication out of the IPCC report at all costs, "even if we have to redefine what the peer-review literature is!"

Jones failed in the end, but he did manage to smuggle a devastating sentence into the IPCC report, which states that McKittrick's findings were "statistically insignificant" -- in other words, meaningless.

Regaining Lost Trust

German climatologist Hans von Storch now wants to see an independent institution recalculate the temperature curve, and he even suggests that the skeptics be involved in the project. He points out, however, that processing the data will take several years.

"There is no other way to regain the trust that has been lost," he says, "even if I'm certain that the new curve will not look significantly different from the old one."

And if it does? "That would definitely be the worst-case scenario for climatology. We would have to start all over again."

Other central predictions of climatologists, such as that involving a noticeable rise in sea levels, would also have to be reevaluated. How high sea levels will go in the future is already a matter of debate.

The Reality of Rising Sea Levels

They could have been scenes from a horror film: New York's skyscrapers jugged out of the ocean like reefs, while cities like Hamburg and Hong Kong, London and Naples had been flooded long ago. Entire countries had been swallowed up in other places. Denmark, the Netherlands and Bangladesh had ceased to exist.

A quarter of a century ago, climatologists grabbed the public's attention with such horrific visions. At the time, the experts calculated that the sea level would rise by more than 60 meters (197 feet) if the greenhouse effect caused all of the Earth's ice to melt.

No one talks about such nightmare scenarios today. None of the current simulations involves the complete melting of the Antarctic ice sheet. On the other hand, hardly any glaciologists doubt that sea levels will be significantly higher along coastlines by the end of the century. But how much higher, exactly? Estimates range from 18 centimeters (7 inches) to 1.90 meters (6' 3").

Hard to Calculate

"Of course, this isn't a satisfactory statement for coastal planners and politicians," admits Peter Lemke, chief climatologist at the Alfred Wegener Institute for Polar and Marine Research in the northern German port city of Bremerhaven. "But we can't sell something as certainty if we don't know exactly what it will be."

The current IPCC report mentions a relatively conservative range of 18 to 59 centimeters. "Most experts consider this estimate to be too small," says Lemke.

Two factors influence the sea level. The first one affects it directly: When water heats, it expands. This warming effect, which can be calculated with relative precision, is expected to cause the sea level to rise by about 22 centimeters by 2100.

Another effect that is not as easy to calculate is the melting of mountain glaciers and inland ice in Greenland and Antarctica. Most of the melting today is happening in mountain glaciers, from the Andes to the Himalayas. According to IPCC calculations, this melting activity contributes 0.8 millimeters a year to the rise in sea level. Greenland and Antarctica each contribute another 0.2 millimeters.

Quicker Melting

Meanwhile, satellite observations indicate that the rate at which the ice is melting has increased. Glaciologists speculate that parts of the Western Antarctic and, to a greater extent, Greenland, are melting more quickly than initially assumed.

But many scientists are reluctant to make new predictions, because the inner processes in the gigantic ice caps remain insufficiently understood. Reliable data on the behavior of calving glaciers has only existed for about 10 years.

Greenland's glaciers are currently spitting a particularly large amount of ice into the ocean. After such a phase, however, many ice flows become dormant again for a longer period of time.

Lemke, like most of his fellow scientists, expects the sea level to rise by somewhere between half a meter and one meter.

Build dikes or get out of the way -- this is the principle coastal residents have applied for years to defend themselves against the forces of nature. In Hamburg in northern Germany, storm surges are now more than half a meter higher than in the 1960s. This is not the result of climate change, however, but of the narrowing of the Elbe River. Nevertheless, the port city is not as threatened as it once was, thanks to improved flood protection.

But storm surges aren't just caused by rising sea levels. Another factor that is at least as important is the wind, which pushes large amounts of water against coastlines.

Can we truly expect to see stormier times in a greenhouse climate?

The Myth of the Monster Storm

Hurricane Katrina had hardly devastated the southern US city of New Orleans five years ago before a "hurricane war" broke out among US scientists. The alarmists, using the rhetoric of fiery sermons, warned that Katrina was only the beginning, and that we would soon see the advent of superstorms of unprecedented fury. Members of the more levelheaded camp were vehemently opposed to such predictions and insisted that there was no justification for such fears.

The dispute escalated when Kevin Trenberth, a climatologist and a lead author of the IPCC report, announced at a press conference at Harvard University that there was a clear relationship between global warming and the increased intensity of hurricane activity. Chris Landsea, a meteorologist with the National Hurricane Center in Miami, was so furious over this unfounded prediction that he withdrew from his participation in the IPCC.

Now the two rivals have reached a surprising truce, and Landsea has largely prevailed with his reassuring assessment.

Last month Landsea, together with top US hurricane researchers, published a study that finally disproves the supposed link between hurricanes and global warming. The study concludes with the assessment that "tropical cyclone frequency is likely to either decrease or remain essentially the same." Top wind speeds could increase somewhat, says Landsea, but the changes would "not be truly substantial."

Setback for the IPCC

The all-clear signal on the hurricane front is another setback for the IPCC. In keeping with lead author Kevin Trenberth's predictions, the IPCC report warned that there would be more hurricanes in a greenhouse climate. One of the graphs in the IPCC report is particularly mysterious. Without specifying a source, the graph suggestively illustrates how damage caused by extreme weather increases with rising average temperatures.

When hurricane expert Roger Pielke, Jr. of the University of Colorado at Boulder saw the graph, he was appalled. "I would like to discover this sort of relationship myself," he says, "but it simply isn't supported by the facts at the moment."

Pielke tried to find out where the graph had come from. He traced it to the chief scientist at a London firm that performs risk calculations for major insurance companies. The insurance scientist claims that the graph was never meant for publication. How the phantom graph found its way into the IPCC report is still a mystery.

At first, the fear of monster storms seemed easily justified. Scientists conjectured that as the oceans became warmer, hurricanes would accumulate more energy. But, as is so often the case, the truth is more complicated. A specific set of conditions must be present in the atmosphere to allow a hurricane to develop and survive. "Wind shear can destroy a hurricane in an early stage," says Landsea, who flies into storm cells in research aircraft every year. Wind shear, however, is likely to increase in a warmer climate. For this reason, many computer models now even point to a decline in hurricane activity.

'Nothing Will Change'

Hurricanes have in fact increased since the late 1960s, a phenomenon scientists attribute to a natural cycle in ocean currents. The constantly rising insurance claims reported by reinsurance companies are a particularly unreliable indicator. "When you adjust for the growth in new buildings, road and factories being built in hurricane regions, there is no longer any evidence of an upward trend," Pielke explains.

The prognoses for all storms outside the tropical zone are even clearer. There has been a widespread fear that rising temperatures would lead to more and more powerful storms.

But current long-term forecasts offer no evidence of such a trend, especially not in the temperate latitudes. "All computer models show that nothing will change at all outside the tropics," says Jochem Marotzke, director of the Hamburg Max Planck Institute for Meteorology (MPI-M). "In the future, we will see neither more nor stronger storms gathering over our heads."

In a greenhouse climate, only the storm paths in low-pressure zones are likely to change. There will probably be more wind in Scandinavia and less wind in the Mediterranean region. In Central Europe, on the other hand, no noticeable changes are expected.

It is easy to explain, in physical terms, why stormier times do not lie ahead for most of the world's regions. According to the models, the high latitudes will heat up more substantially than the equatorial zones (which also explains why climate change is already so visible in the Arctic regions). On balance, temperature differences on the Earth's surface will decrease, which in turn will even reduce wind speeds -- meaning the much-feared monster storms are unlikely to materialize.

Climate Change's Winners and Losers

Even though researchers have been refining their climate models for more than 30 years, there is one natural phenomenon that continues to elude them. "Clouds still pose the biggest problem for us," says Marotzke. "The uncertainties are still very big. This remains the most important issue for us."

It all seems simple enough in theory. When temperatures rise, more moisture evaporates. But does that mean that more clouds form as a result? And if so, do they curb or accelerate global warming?

On their upper surfaces, clouds act like mirrors. They reflect sunlight back into space, thereby cooling the atmosphere. But on their lower surfaces they prevent the heat reflected by the Earth from escaping, and temperatures rise.

Which of the two effects predominates depends on the height and type of clouds. "You just have to look up to see how many different types there are," says US cloud expert Björn Stevens, the new director of the MPI-M. "And each cloud type behaves differently."

'The Jury Is Still Out'

Until now, no one knew exactly which clouds benefit from a greenhouse climate. But the answer to this question determines whether average global temperatures will end up being one degree higher or lower than predicted by today's models, a factor which creates significant uncertainty. "The jury is still out on which direction the pendulum will take," says Stevens.

Despite the enormous uncertainties, there is agreement on at least one issue: Global warming can no longer be stopped.

But would that be as horrific as has been predicted? Does humanity truly face plagues of biblical proportions? Won't a warmer climate also have its benefits? And won't it lead to higher crop yields and more tourism revenues in many places?

The truth probably lies somewhere in the middle. There will undoubtedly be losers, but there will also be winners. Whether global warming is more likely to be harmful or beneficial depends entirely on the location of the observer.

Imprecise Simulations

Unfortunately, the computer simulations that predict the climate of the future are still too imprecise to be able to draw reliable conclusions for each individual country or region. Although it is relatively easy to predict the amount by which average temperatures will probably rise in different parts of the world, the models are still relatively shaky when it comes to precipitation. In fact, the prognoses the different models make are sometimes very contradictory.

Nevertheless, a clear trend is emerging in most simulations. "In places where it already rains a lot today, it will rain even more," says Erich Roeckner, a veteran climatologist who has spent years simulating changes in precipitation in a warmer climate. "And where it's dry today, it'll be even drier in the future."

The common myth that developing countries, the poorest of the poor, will suffer the most as a result of climate change is wrong -- at least according to current climate models.

In central Africa, for example, the models predict that hardly anything will change, and precipitation will likely remain constant. And according to most simulations, precipitation could even increase in the drought- and famine-plagued Sahel. "If this turns out to be true," says Roeckner, "it will of course be a surprisingly positive side effect."

Clear Winners of Climate Change

The clear winners are principally the northern regions of the world where it has up until now been too cold and inhospitable. Countries like Canada and Russia can look forward to better harvests and blossoming tourism. The countries bordering the Arctic also hope that the melting of sea ice will enable them to reach previously inaccessible natural resources. For Scandinavians, for example, the only drawback will be a possible guilty conscience over the fact that they are benefiting from climate change.

It will become more arid, however, in many subtropical regions. Industrialized nations, which bear the greatest culpability for global warming, will be most heavily affected. The new drought zones will probably lie in the southern United States and Australia, as well as in South Africa. In Europe, Mediterranean countries like Spain, Italy and Greece will struggle with even drier climates than they already have today.

A drastic shift could take place in the European tourism business, as climate change heralds bad times for the large tourist developments in southern Spain and good times for hotels along the North Sea and Baltic Sea coasts. "If I had a vacation house on Mallorca," Max Planck scientist Jochem Marotzke jokes, "I would sell it and look for one on (the Baltic Sea island of) Usedom."

A Mediterranean Climate in Germany?

Germany could be among the beneficiaries of climate change. A Mediterranean climate could prevail there by the end of the century, which would mean that summer temperatures in Hamburg, in the north, would be as warm as they are in the southwestern city of Freiburg today, while Freiburg's summers would come to resemble those of Marseilles today. Perhaps palm trees would even grow on the North Sea island of Helgoland.

But there are also downsides. While it will be drier in the summer, rainfall will increase significantly in the fall and winter. Northern Germany, in particular, could see more flooding. To avoid flooding, it will be necessary to improve drainage on fields and pastures and reestablish old flood plains.

In particularly dry regions, on the other hand, such as the eastern state of Brandenburg, the risk of forest fires will increase even more than it has already as a result of the global warming that has already occurred. Paradoxically, the amount of land affected by fire has declined considerably since 1970, even though there are more fires today. This is because optical smoke detectors have now been installed to monitor forests, so that fires are extinguished more quickly. As global warming continues, it could also become necessary to replace pine forests with mixed forests.

For Germans today, who have just experienced an unusually harsh winter, these scenarios are still a long way off. What, some are likely to wonder, do simulations about the world in 100 years have to do with the reality of life today?

Looking into the Near Future

To illustrate the consequences of global warming more vividly, scientists at the MPI-M are currently developing a medium-term scenario: the world in 20 years' time.

"For the first time, we want to try to look into the near future," says MPI-M Director Jochem Marotzke. "This is more difficult, because the fluctuations are bigger than in the long term."

While the supercomputers are still computing away, scientists already estimate that average temperatures will rise by another half a degree Celsius by 2030, or about the same temperature increase since the 1970s. "This will be clearly felt here," says Marotzke.

Germany will see many more tepid summer nights, and spring will begin earlier and earlier. And in only 20 years, snow could become a thing of the past in Germany.

All of this can no longer be averted.

Delayed Reaction

Even if humanity were to stop burning coal, oil and natural gas immediately, there would still be a moderate temperature increase in the next two to three decades. This is because the planetary weather system reacts with a certain delay to the greenhouse gases that have already been emitted into the atmosphere.

One of the biggest unanswered questions is whether it will be possible to keep the temperature increase at less than two degrees Celsius, as world leaders agreed at the climate summit in Copenhagen.

Critics pose a completely different question: How slavishly must humanity stick to this target? Will it truly be the end of the world if this threshold is exceeded?

The Invention of the Two-Degree Target

Climate models involve some of the most demanding computations of any simulations, and only a handful of institutes worldwide have the necessary supercomputers. The computers must run at full capacity for months to work their way through the jungle of data produced by coupled differential equations.

All of this is much too complicated for politicians, who aren't terribly interested in the details. They have little use for radiation budgets and ocean-atmosphere circulation models. Instead, they prefer simple targets.

For this reason a group of German scientists, yielding to political pressure, invented an easily digestible message in the mid-1990s: the two-degree target. To avoid even greater damage to human beings and nature, the scientists warned, the temperature on Earth could not be more than two degrees Celsius higher than it was before the beginning of industrialization.

It was a pretty audacious estimate. Nevertheless, the powers-that-be finally had a tangible number to work with. An amazing success story was about to begin.

'Clearly a Political Goal'

Rarely has a scientific idea had such a strong impact on world politics. Most countries have now recognized the two-degree target. If the two-degree limit were exceeded, German Environment Minister Norbert Röttgen announced ahead of the failed Copenhagen summit, "life on our planet, as we know it today, would no longer be possible."

But this is scientific nonsense. "Two degrees is not a magical limit -- it's clearly a political goal," says Hans Joachim Schellnhuber, director of the Potsdam Institute for Climate Impact Research (PIK). "The world will not come to an end right away in the event of stronger warming, nor are we definitely saved if warming is not as significant. The reality, of course, is much more complicated."

Schellnhuber ought to know. He is the father of the two-degree target.

"Yes, I plead guilty," he says, smiling. The idea didn't hurt his career. In fact, it made him Germany's most influential climatologist. Schellnhuber, a theoretical physicist, became Chancellor Angela Merkel's chief scientific adviser -- a position any researcher would envy.

Rule of Thumb

The story of the two-degree target began in the German Advisory Council on Global Change (WBGU). Administration politicians had asked the council for climate protection guidelines, and the scientists under Schellnhuber's leadership came up with a strikingly simple idea. "We looked at the history of the climate since the rise of homo sapiens," Schellnhuber recalls. "This showed us that average global temperatures in the last 130,000 years were no more than two degrees higher than before the beginning of the industrial revolution. To be on the safe side, we came up with a rule of thumb stating that it would be better not to depart from this field of experience in human evolution. Otherwise we would be treading on terra incognita."

As tempting as it sounds, on closer inspection this approach proves to be nothing but a sleight of hand. That's because humans are children of an ice age. For many thousands of years, they struggled to survive in a climate that was at least four degrees colder than it is today, and at times even more than eight degrees colder.

This means that, on balance, mankind has already survived far more severe temperature fluctuations than two degrees. And the cold periods were always the worst periods. Besides, modern civilizations have far more technical means of adapting to climate change than earlier societies had.

Since the first rough estimate was made, many other good reasons have emerged to support the two-degree target, says Schellnhuber. At the same time, however, the constant appearance of new studies has also made the picture significantly more complex.

Coral reefs, for example, could already be doomed if the oceans heat up by 1.5 degrees Celsius. On the other hand, crop yields in agriculture are likely to rise at temperature increases of up to 2.5 degrees Celsius -- good news for the world's growing population.

Completely Speculative

But what good are all the predictions? It's difficult enough to calculate exactly how far temperatures will rise in the coming decades. It becomes completely speculative to predict in detail how warming temperatures will benefit tourism or harm biodiversity.

"Of course, the conclusions of climate impact research are not as reliable as we'd like them to be," Schellnhuber admits. "But we can't exactly drop 10,000 studies from *Science* and *Nature* on our political leaders' desks. That would obviously be too much for them. Instead we, as experts, must attempt to condense the large number of analyses into plausible scenarios."

Critics say that the climate impact researchers have gone too far with their brand of political advice. "The two-degree target has little to do with serious science," says Hans von Storch. Many of his fellow scientists, he adds, now see themselves too much as political activists who want to get something done. This, in turn, harms the credibility of science as a whole, he adds, and it is also a more deep-seated cause of the Climategate affair and the sloppy work on the IPCC report.

"Unfortunately, some of my colleagues behave like pastors, who present their results in precisely such a way that they'll fit to their sermons," says Storch. "It's certainly no coincidence that all the mistakes that became public always tended in the direction of exaggeration and alarmism."

'Completely Absurd'

Such suspicions irritate PIK Director Hans Joachim Schellnhuber, particularly when they are directed against him or his institute. Schellnhuber, a native of Bavaria, normally speaks quietly and diplomatically, but he raises his voice when discussing the accusations. He says that he is far from being an environmental activist or someone who acts purely for political reasons.

"That's completely absurd!" he says heatedly. "I don't participate in protest marches, I'm not a member of the Green Party, I like to eat meat and I drive a BMW. And I didn't study physics to become a climatologist, either."

But no, he adds, he happens to be someone who has acquired inside knowledge about a looming disaster, knowledge that he cannot keep to himself. "If I'm a passenger on a ship and I see, through my binoculars, that we're headed for an iceberg," says Schellnhuber, "I have to warn the captain immediately."

But exactly how far away is that iceberg? How much time is left to steer the ship onto an alternate course? And how great is the risk of collision? These are key questions. In reality, it isn't about stopping a luxury ocean liner, but about the massive effort that is required to end the age of oil and coal as quickly as possible.

Time to React

"We climatologists can only describe possible futures," Storch points out. "It's also possible that things will be completely different."

Storch, a native of northern Germany and one of the pioneers of climate modeling, recommends a more dispassionate approach. He grew up on the North Sea island of Föhr, where he experienced storm tides at first hand. He learned that humans are tough and adaptable beings.

"Fearmongering is the wrong way to go about it," says Storch. "Climate change isn't going to happen overnight. We still have enough time to react."

Translated from the German by Christopher Sultan

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